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Ant Diversity on Urban Green Rooftops

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Ant Diversity on Urban Green Rooftops

Abstract
Green rooftops serve as potential habitats for organisms in urban environments. We studied patterns in ant species richness across eight green rooftops in Chicago and surrounding suburbs. We compared ant-sampling methods, ant species composition between rooftops and bases, and ant species richness between certain rooftop characteristics. On average pitfall traps captured significantly more ant species, and ant species on rooftops were a subset of the species around their bases. This study shows a green rooftop's potential as a habitat for ants in urban "concrete jungles," providing us further reasoning to study rooftop communities as we continue to make cities green.

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LAKE FOREST COLLEGE

Senior Thesis

Ant Diversity on Urban Green Rooftops

by

Kaya Cuper

April 15, 2014

The report of the investigation undertaken as a
Senior Thesis, to carry two courses of credit in
the Department of Biology

Michael T. Orr
Krebs Provost and Dean of the Faculty

Sean B. Menke, Chairperson

Amy Abe

Douglas B. Light

Abstract

Green rooftops serve as potential habitats for organisms in urban environments. We studied patterns in ant species richness across eight green rooftops in Chicago and surrounding suburbs. We compared ant-sampling methods, ant species composition between rooftops and bases, and ant species richness between certain rooftop characteristics. On average pitfall traps captured significantly more ant species, and ant species on rooftops were a subset of the species around their bases. This study shows a green rooftop's potential as a habitat for ants in urban "concrete jungles," providing us further reasoning to study rooftop communities as we continue to make cities green.

Dedication

I would like to dedicate this thesis to those who believed in me as a student and researcher by offering me advice, support, and the opportunity to conduct this research. I would also like to dedicate this to my family and my brother Dante.

Acknowledgments

I would like to thank my committee members for mentoring me during my research for this thesis and throughout my time here at Lake Forest College. Without them I would not have been able to bring this research to a thesis-worthy standard.

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Chapter 1 – Introduction to Green Rooftops

Urban environments all over the world have unfolded into concrete jungles filled with high-rises, skyscrapers, and paved roads. Increasing number of cars, concrete, and people result in larger cities with rising temperatures and higher rainfall runoff (Oberndorfer et al. 2007; Franczyk & Chang 2009), and the destruction of natural environments, which are home to a variety of plants and animals (Mckinney 2006). Due to the rising human population and increasing urbanization, ecologists are attempting to determine effective ways of preserving and adding green space into cities, with the hope of transforming the concrete jungle back into livable green habitats. Green rooftops, rooftops with layers of soil and vegetation, offer solutions to the loss of natural environments due to urbanization. These green islands of the sky may help reduce the urban heat island effect, aid with storm-water management, and provide natural environments as refugees for organisms all over cities (Oberndorfer et al. 2007). Green rooftops not only reduce negative environmental impacts, but also the economic issues relating to heating, cooling, and roof maintenance (Clark & Talbot 2008). Finally, rooftops are not only aesthetically pleasing, they also are an essential and innovative way of making cities green again.

In the late 20th century, individuals began building green rooftops worldwide because green rooftops benefited cities ecologically and economically. Though green rooftops may appear a new ecological advancement, they date back to one of the Seven Wonders of the World, where rooftops gardens were documented in hanging gardens of Semiramis around 500 B.C. (Getter et al. 2006; Oberndorfer et al. 2007).

Today a green rooftop is considered “a vegetated roof or deck designed to provide urban greening for buildings” (Dvorak 2010). Modern green rooftops first originated in the 20th century in Germany where vegetation was installed on rooftops to help protect the roofs from solar radiation (Oberndorfer et al. 2007). Since roofs were made of a flammable tar in the 1880s, the roofer H. Koch decided to cover his rooftops with sand and gravel, which eventually was colonized by plants (Getter & Rowe, 2006). By 2006, Germany had constructed more than 800 green roofs that comprise 10% of all flat roofs (Sonne 2006). Alternatively, in the U.S. the first modern rooftop was built on the Rockefeller Center in the year 1930 during the Great Depression (Osmundson 1999; Getter et al. 2006). Green rooftops are no longer novel, in fact, Chicago now has more green roofs than any other U.S. city, and added 600,000 more square feet of green roofs in 2009 (Stutz 2010). Chicago currently has 600 projects that will bring its total to 7 million square feet (Stutz 2010). Washington, D.C. added 190,000 square feet in 2009 and has set a goal of 20 percent green roof coverage by 2020 (Stutz 2010). Today, the functionality and appearance of these rooftops continues to inspire building owners globally to build green islands in the sky.

Green rooftops are built in a variety of ways, leading to differences in the way they are used and their effectiveness in lowering building temperatures and rainfall runoff across cities. Green rooftops are built with a drainage layer to drain excess water, a growing medium to help vegetation thrive, and finally the vegetation layer itself (Fig. 1, Getter & Rowe 2006). There are two main types of green rooftops, extensive and intensive, with differing growing medium weights allowing the growth of small or large plants. For instance, extensive green roofs are a modern modification of the roof-garden concept. They typically have shallower substrate, require less maintenance, and are strictly more functional than intensive green rooftop gardens, which are built for their aesthetic beauty because they house larger shrubs with their deeper soil depths (Dunnett and Kingsbury 2004; Getter & Rowe 2006). Extensive green rooftops, thus, have smaller plants and mosses and only cost $10 to $30 per square foot (Orbendorfer et al. 2007). In comparison, intensive green rooftops with deeper soil depths require more maintenance and can support larger shrubs and trees (Orbendorfer et al. 2007). Intensive rooftops tend to be more user friendly, allowing individuals to access and walk across these rooftops (Orbendorfer et al. 2007). The way these rooftops are built can help influence their benefits on the urban heat effect and storm-water management.

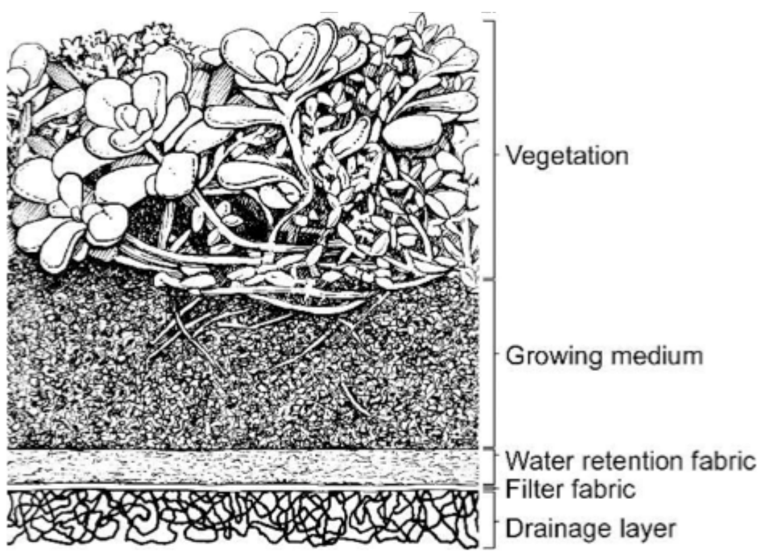

Figure 1. Layers compromising a green rooftop. Reprinted from Getter & Rowe, 2006.

One of the major problems of urbanization is rising temperatures in cities, also called the urban heat effect or urban heat island effect. The urban heat effect is where urban regions are significantly warmer than surrounding suburban and rural areas (Oberndorfer et al. 2007). The HadAM3 Global Climate Model, developed for climate modeling, showed that that regions of high population growth correlate with regions of high urban heat, commonly seen in the Middle East, the Indian subcontinent, and East Africa (McCarthy 2010; Pope et al. 2000). Helping control this heat is essential to human society because raising temperatures may affect human health, energy, air pollution, and water use and management (Heisler & Brazel 2010; Taha 1997). McCarthy (2010) predicts that by 2050, the number of urban dwellers will reach 6 billion, causing climate changes in cities due not only to air pollution but also the urban heat island. The urban heat island, thus, may increase as populations and cities grow.

Around the world, countries with larger urban areas report greater urban and rural temperature contrasts. The urban heat island is measured by air temperature using automobile transects and weather station networks or in surface temperatures through the use of airborne or satellite remote sensing (Streutker 2003). In Poland, Fortuniak (2006) found that having considerable cloud cover and strong winds prevent high urban–rural thermal contrast on the majority of nights. Mobile measurements showed that the center of Lodz Poland can be up to 12 °C warmer than rural areas (Fortuniak 2006). Similarly, in Barrow Alaska, Hinkel et al. (2003) demonstrated that during winter, the urban area averaged 2.2 °C warmer than more rural areas. The strength of urban heat island effect increased as the wind velocity decreased, reaching an average value of 3.2°C under calm conditions (Hinkel et al. 2003). In Granada Spain, Montavez (2000) found similar results where the growth of the city has resulted in a large increase in minimum temperatures and small decrease in maximum temperatures. The urban heat island changes between city and rural areas, and can also change from the ground-up in a city.

An urban heat island can be found around a building, a vegetative canopy, and finally throughout the city (Taha 1999). Some of regions of a city have been characterized into distinct layers called the urban canopy layer and urban boundary layer (Fig 2., Oke 1976). The urban canopy layer, roughly from ground to roof level of a city, is directly affected by its immediate surroundings, where the processes of airflow and energy exchange are controlled by site-specific characteristics such as building materials and the geometry of the buildings (Climatol 2003; Oke 1976). The urban boundary layer, which is above roof level of a city, is affected by the presence of the urban area below (Climatol 2003). The urban heat boundary layer is mainly caused by anthropogenic heat, where the heat that is generated comes from the sun in the form of solar radiation, power plants, automobiles, and air-conditioners (Rizwan 2007). Solar radiation is reflected in cities due to large amounts of buildings decreasing sky-view, not much vegetation, and roughness of structures like cement and asphalt that store and radiate heat (Rizwan 2007). Taha et al. (1997) found that anthropogenic heating can affect the near-surface air temperature and potentially play a role in creating urban heat islands. However, combining anthropogenic heating in cities with low vegetation cover and dark surfaces can synergistically increase the urban heat island. The use of high albedo building material and proper building design can be used to reduce anthropogenic heat.

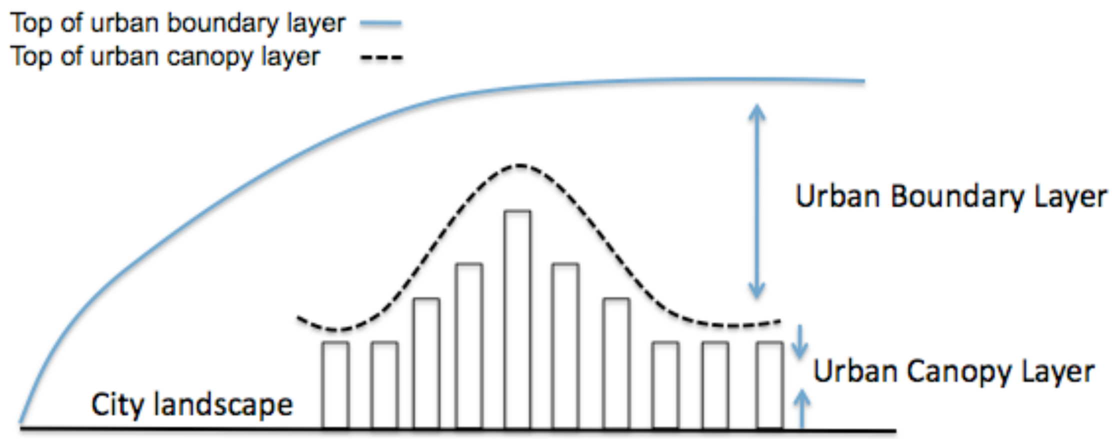

Figure 2. A representation of the distinct layers of the urban heat island in a city. Redesigned from Getter & Rowe (2006).

Increasing the albedo and the evapotranspiration of a surface are mechanisms to decrease the urban heat island. The albedo of a surface is defined as its "hemispherically and wavelength-integrated reflectivity" (Taha et al. 1997) or the energy of sunlight reflected from a surface (Akbari et al. 2009). Using high albedo materials reduces the amount of solar radiation absorbed through building envelopes and urban structures and keeps their surfaces cooler. It is believed that the albedo, the reflected light in comparison to the incident light, is also very low in cities causing high air temperatures (Rizwan 2008). Lower albedo is due in part to darker surface materials making up cities and also to the effects of trapping shortwave radiation by the vertical walls and the urban, canyon-like morphology (Heisler & Brazel 2010). For instance, typical measured albedo of a black roof is 0.05, whereas a high-reflective white membrane has an initial albedo of 0.8, and green rooftops have an albedo between 0.75-0.80 (Getter & Rowe 2006). Green rooftops help decrease the urban heat island, by providing vegetation and layers of insulation to help reduce temperatures in buildings themselves but also in the area around them.

Decreasing ground space and green space, due to urbanization, makes it difficult to find technologies to decrease the urban heat island. However, with the use of roof space, high temperatures of the urban heat island may be tackled. In estimates by Akbari and Rose (2001, 2003, 2008), pavement and roofs constitute over 60% of urban surfaces with rooftops accounting for 20-25%, and pavement accounts for about 40%. Two main mitigation efforts to transform rooftop environments and to help decrease the urban heat island are cool or reflective roofs (Akbari & Levinson 2008; Santamouris 2012) and green or living roofs (Santamouris et al. 2007; Santamouris et al. 2012). Reflective rooftops are made through a variety of materials that have a high reflectivity value in the infrared spectrum (Levinson et al. 2005), however there are larger benefits to having green rooftops.

Rooftops with reflective barriers or vegetation show correlations with lower temperatures in surrounding environments. Technologies aiming to increase the albedo of cities through the use of vegetative green roofs appear to be very promising in decreasing heat in cities (Santamouris 2012). For instance, Bass et al. (2002), through a regional simulation model using 50% green-roof coverage distributed evenly throughout Toronto, showed temperature reductions as great as 2°C in the city. Susca (2011) also found, when monitoring the urban heat island in four areas of New York City, an average of a 2°C difference of temperatures between the most and the least vegetated areas in comparison to "man-made" materials. Air temperatures above the building have been shown to be 3 °C lower when vegetated compared with a conventional roof (Wong 2003; Getter & Rowe 2006). Overall green rooftops are solutions to decreasing higher urban temperatures as reflective surfaces.

Green rooftops address urban heat islands through the use of its vegetation as a source of solar reflection and water evaporation. Solar radiation, the external building temperature, and the relative humidity are reduced with the addition of vegetation to green rooftops (Niachou et al. 2001). The plants for their biological functions, such as photosynthesis, respiration, transpiration, and evaporation absorb a significant proportion of the solar radiation (Niachou et al. 2001). Evapotranspiration, the evaporation and transpiration of water during plant respiration, shading by vegetation, and the increasing insulation from soil and vegetation are an effective mitigation of near-surface climates (Taha 1997; Orbendorfer et al. 2007). Due to a lower absorption of solar radiation and lower thermal conductance, the addition of a green roof is estimated to reduce annual energy consumption by just over 1% per building (Saiz et al. 2006). By absorbing water runoff, green rooftops provide another way of reducing temperatures and the overflow of water in the sewage systems of concrete filled cities.

Urbanization has dramatically decreased the amount of surface absorption of water due to the increase in impervious surfaces (Carter 2006). Excessive runoff, due to this lack of surface absorption, increases the chances for flooding resulting in property damage, the overwhelming of sewer systems, and human harm (Getter & Rowe 2006). There are increased chances of flooding when combined sewer systems, those that take wastewater and storm water to treatment plants, consist of a single pipe (Getter & Rowe 2006). When storm water exceeds the capacity of sewer pipes, the combined sewage can overflow into relief points, resulting in raw waste being dumped into waterways (Getter & Rowe 2006). In New York City, about half of all rainfall events result in the occurrence of untreated waste, approximately 40 billion gallons, end up in New York's surface waters per year (Getter & Rowe 2006). Green rooftops thus may provide solutions to flooding in cities by delaying the initial time of runoff due to the absorption of water in the green roof and distributing the runoff over a longer time period through a slow release of excess water stored in the pores of the substrate (Mentes 2006). Research has shown rooftops can be innovatively used to capture this water excess (Moran et al. 2004; Getter & Rowe 2006).

Rainfall or excess water runoff is slowed down when absorbed throughout the multiple layers of a green rooftop. Runoff is delayed because it takes time for the media to become saturated and for the water to drain through the media (Getter & Rowe 2006). This delay can prevent storm water sewer systems from overflowing, by allowing it to process runoff for a longer time at a lower flow rate. Green roofs can delay runoff between 95 minutes (Liu 2003; Getter & Rowe 2006) and 4 hours (Moran et al. 2004; Getter & Rowe 2006), compared with the normal roofs for which runoff was nearly instantaneous. Using data from 628 rooftops, Mentes (2005) predicted that adding green rooftops on just 10% of the buildings in Brussels, Belgium would result in a runoff reduction of 2.7% for the region and of 54% for the individual buildings. Another study by Simmons (2008) on six green rooftops showed that maximum runoff retention was 88% and 44% for medium and large rain events. Respectively, rooftop with lower slopes also decreases runoff, and when they are combined with deeper soil depths, this can decrease runoff over time beyond the time it is actually raining (VanWoert et al. 2005). Green rooftops help mitigate many of the environmental problems of urbanization, but they also help relieve health problems among people.

Other than the physical implications of green rooftops that help decrease temperatures and storm-water runoff, they also help people have better physical health and well-being. Maas et al. (2006) has shown that the percentage of green area within a one to three kilometer radius has a significant relation to perceived general health of a person. Elderly, youth, and secondary educated individuals living in large cities benefited the most from living near green spaces (Maas et al. 2006). The relationship between stressful life events, the number of health complaints, and perceived general health can be moderated by an increasing amount of green space in a 3-km radius (Van de Berg et al. 2010). Finally, even exercising in a green environments can have the positive effects in reducing blood pressure, in terms of the average reduction in mean arterial blood pressure (Pretty et al. 2005). Green rooftops, thus, affect communities by giving individuals a more positive perception of their health.

Beyond aesthetic and health reasons, green rooftops or in general green area creates higher property values. Luttik (2000) compared 3000 house transactions in eight regions of the Netherlands and demonstrated that house price can increase by 8-10 percent when overlooking water or even by 6-12 percent when overlooking an open space. Fuerst and McAllister (2011) showed through the comparison of 24,479 office buildings in 81 metropolitan areas spread throughout the United States that eco-certified buildings have higher rental and sale prices. Overall green rooftops are not only a positive influence on the environment, but they also stimulate economies by driving higher property values. Furthermore these aesthetically pleasing and healthy environments for humans can be maintained with animals.

Green rooftops provide homes for a variety of animals, many of which are endangered. The studies of animals on green rooftops have focused on spiders, bees, and birds. For example, Coffman and Waite (2010) found that green rooftops serve as alternative habitats by harboring insects, spiders, and birds. Endangered species have been recorded on rooftops in places like Switzerland where 78 spider and 254 beetle species were identified during the first 3 years across 17 rooftops, and 18 percent of those spiders and 11 percent of the beetles were listed as endangered (Getter & Rowe 2006). In Switzerland, northern lapwings, whose populations are being threatened though the transformation of wetlands for agricultural use, have begun to breed on some green roofs, though not always successfully (Baumann 2006). Green rooftops are also used to house beehives in urban environments and because North America is experiencing large declines of these pollinators, studies have been conducted in sampling bees on green rooftops in Toronto, Ontario (Colla et al. 2009). Colla et al. (2009) and Tonietto et al. (2011) in Chicago have shown that green rooftops support a variety of bee species showing the success of these vegetated rooftops in providing habitats for organisms, even when they are endangered or experiencing significant declines. Green rooftops provide animals with alternative habitats, but also and provide soil for plants to flourish.

Green rooftops have provided ways of creating new habitats for plants, which in return make cities greener for individuals to enjoy. In Switzerland, nine orchid species and other rare and endangered plant species were found on a 90 year old green rooftop (Brenneisen 2006). Native plant species can be successfully grown, as shown when 35 native grasses and wildflowers successfully grew on an irrigated intensive green roof in Utah (Dewey et al. 2004). On the other hand, other studies have also found that not all vegetation can withstand the environmental stresses of strong wind, rain, and sometimes drought typical of green rooftops (Carter & Butler 2008). In Athens Georgia and St. Louis Missouri, hardy plants like Sedum were better able to survive harsh weather conditions than native species (Carter & Butler 2008). After a summer with no irrigation, only 2 of the 15 native plants survived in comparison to 100% of Sedum species (Carter & Butler 2008). Whether the habitats for plants or animals are altered through urbanization, green rooftops have shown to be a successful alternative environment for organisms to colonize.

Rooftops are not only a beautiful oasis to enjoy in a concrete jungle, but are beneficial to the environment and health of human beings (Pretty et al. 2005, an de Berg et al. 2010). However, there are many questions that have not been answered regarding rooftops and their arthropod communities. There is a lack of research concerning the sampling of insect communities across a diversity of green rooftops or over long periods of time. It is important to study these organisms because they can further provide us the knowledge regarding the success of green rooftops as novel habitats in urban cities.

Chapter 2 - Ant Diversity of Urban Green Rooftops

Introduction

Green rooftops can be compared to islands of the sky that are isolated by concrete and the buildings between them. These isolated islands in the city landscape are thus relatable to other isolated habitats, such as oceanic islands and fragmented forests altered by human action. The equilibrium theory of island biogeography predicts that isolation, area, and age are important determinants of species richness (Simberloff & Abele 1976). Characteristics of green rooftops such as building height, soil depth, plant community composition, and rooftop age may be equivalent to isolation, area and age of oceanic islands. Therefore, these may be factors that predict arthropod species richness of rooftop islands.

The equilibrium theory of island biogeography suggests that the number of species is determined by the equilibrium between the colonization and extinction rates (Lassen 1975). Smaller areas with smaller populations exhibit higher extinction rates because there are greater chances of breeding failure and mortality (Simberloff & Abele 1976). This theory of island biogeography can be compared to the insect colonization of green rooftops in cities because green rooftops vary in area and height. The height of green rooftops is analogous to the isolation of islands in the biogeography theory, where the farther the distance between the island and its immigrants, there is a lower rate of colonization (Lassen 1975). The equilibrium theory of island biogeography also predicts that as islands get larger, species diversity increases (Kohn & Walsh 1994). This is due in part because vegetation complexity increases allowing more types of species to colonize (Kohn & Walsh

1994). Green rooftop areas with greater vegetative complexity may allow more species to thrive. In order to understand if the equilibrium theory of island biogeography can be applied to green rooftops, studying the patterns of insect species richness can help understand these relationships.

Insect species are ideal for ecological studies because of their ability to be used as bio-indicators, where they indicate the health of an environment and the species richness of other organisms (Phillpott et al. 2005; Dunn et al. 2007). Insects are preferred as bio-indicators because they respond quickly to environmental stress, have short generation times, and are easily sampled and identified (Peck et al. 1998). In order to be chosen as a bio-indicator, organisms need to (1) provide early signs for environment change, (2) be widely distributed, and finally (3) be easy and cost effective to measure (Noss 1990). Ants, for instance, are ideal organisms to use as bio-indicators.

Ants are ecologically important and can provide early signs of change because they are found in a variety of biomes as seed dispersers, floral protectors, and even soil cyclers (Lobry de Bruyn et al. 1990; Phillpott et al. 2005; Dunn et al., 2007). Ants, as bio-indicators, can be used to learn about environmental quality because they are recognized in responding to ecological changes due to human activity (Anderson et al. 2002). Peck et al. (1998) found that ant species assemblages were correlated with soil variables, tillage practices, and insecticide use after sampling 90 sites in agricultural fields in North Carolina and Virginia. Furthermore, Anderson et al. (2002) showed that ant species richness significantly declined with increasing SO_2 emissions from a large copper and lead smelter at Mt

Isa in the Australian semi-arid tropics. Ants are also distributed globally and highly invasive, because they have high potentials of being transported by humans (McGlynn 1999). This further demonstrates that ant species richness is recorded easily because they are small enough for transport, as seen in their abilities to be highly invasive (McGlynn 1999). Ants are thus potentially a great model to use in determining the effectiveness of green rooftops and their effects on species richness.

Determining the best sampling methods of ants in the novel environment of green rooftops is essential because there have been no studies that have compared ant capture on green rooftops. Ant sampling methods have only been compared in different terrestrial habitats. For instance, terrestrial ants are commonly sampled by pitfall and bait traps. Pitfall traps are easy to use and can be operated continuously during day and night, while also providing a good estimation of species richness and abundance (Wang et al. 2002). Bait traps are easier to operate, faster, and obtain much cleaner samples than pitfall traps, but are influenced by ant feeding preferences, the time of day, and changes in weather (Wang et al. 2002). Studies testing pitfall and cookie baits in temperate forest, such as Cornwall, NY, found that pitfall traps accumulated species significantly more rapidly than cookie baits (Ellison et al. 2007). Even in the more warm temperate regions, pitfall traps predicted 69% of total site species richness, whereas baiting was the least productive in quantifying species richness in five upland regions of Florida (King & Porter 2005). By comparing the ant species captured amongst these methods, a clearer picture can be gained of how these novel green rooftop communities can support ant species richness.

Previous studies of arthropod diversity on green rooftops have compared a variety of their characteristics (Schindler et al. 2011; Madre et al. 2012), however, no studies have specifically used ants. Overall, arthropod communities have been observed on rooftops by comparing their richness to the height, area, size, and complexity of the green rooftop. Schindler et al. (2011) studied the effects of isolation on arthropod diversity, which included ants from the family Formicidae, and found there was no correlation with rooftop area, size, height, or distance to nearest vegetated habitat. Arthropod species richness and abundance, which have included *Camponotus* and *Formica* species, have been shown to be greater at ground level than on their corresponding green rooftops, with a species composition that only differed slightly (MacIvor & Lundholm 2010). There are conflicting results on the relationship between arthropod diversity and habitat complexity on green rooftops, where some studies demonstrate that the amount of vegetation cover may be more important for arthropod diversity on green rooftops than the diversity of the vegetation (Schindler et al. 2011), whereas others appear to show that species richness and abundance of arthropods, where *Lasius neoniger* was the most abundant ant species, is greater on rooftops with more complex vegetation (Madre et al. 2012). My research built upon these studies by focusing on area, age, height, and distance to nearest vegetated habitat as predictors of ant species richness.

To assess the impact of green rooftops as an novel habitat for ants in urban environments, I address three broad questions (1) what is the most efficient method to sample green rooftops for ants, by comparing the effectiveness of pitfall traps and cookie baits, (2) which species colonize this novel environment, by comparing ant species richness between rooftops and the area around their bases, and (3) how rooftop characteristics such as area, age, height, and distance to nearest vegetated habitat affect ant species richness on green rooftops.

Methods

This study was carried out across green rooftops in Chicago and surrounding suburban areas of Illinois between May and August in both 2012 and 2013. I intensively sampled eight green rooftops using pitfall traps and cookie baits (Fig. 1, Table 1). An additional 23 green rooftops were only accessible through the landscaping company Intrinsic Landscaping (Table 1, Appendix A). These rooftops were sampled by workers of Intrinsic Landscaping only using cookie baits.

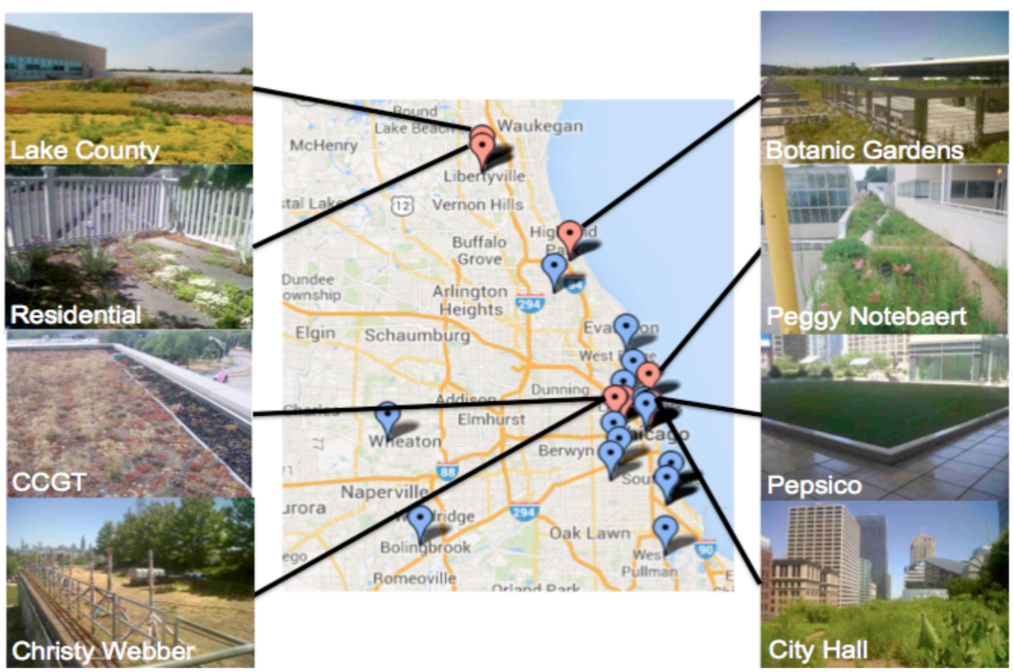

Figure 1. Map of 8 intensively sampled rooftops using pitfall traps and baits (red) and 23 rooftops sampled using baits (blue).

Table 1. Rooftop characteristics of the 8 intensively sampled rooftops.

Green rooftops	Age (Years)	Height (Stories)	Rooftop type	Green rooftop size (m^2)	% Vegetated area in 500 m radius
Botanic Garden	3	1	Intensive/ Extensive	1,486	607,399
Lake Permit County Center	3	1	Extensive	540	138,560
Christy Webber	8	1	Intensive/ Extensive	526	79,681
Residential	8	2	Extensive	24	323,721
Peggy Notebaert	10	2	Intensive/ Extensive	893	626,133
CCGT	11	2	Extensive	243	13,856
Pepsico	11	1	Intensive	354	31,306
City Hall	12	11	Intensive	1,885	3,279

Pitfall Traps

Pitfall traps consisting of 50 mL centrifuge tubes were evenly placed across rooftops every four to five meters, ranging from 6 to 80 pitfall traps per rooftop. Ten pitfall traps were placed around the base of the buildings with the green rooftop. Traps around the bases were evenly placed in the ground, or sometimes in flowerpots or beds around buildings. Pitfall traps were filled with 25 mL of propylene glycol and 1-2 drops of soap, and dug so that their lid was flush with the soil. Rooftops with soil depths of less than 12.7 centimeters had shorter 12 mL pitfall traps placed in them filled with 10 mL propylene glycol and 1 drop of soap. These 12 mL traps were the 50 mL tubes cut to shorter lengths. In 2012, rooftops were sampled once between May and June, while in 2013 rooftops were sampled once between the months of July and August. Pitfall traps were left in the soil closed for one day. After one day, the lids were removed and traps were left open for three days, and then taken out for processing. The same protocol was used for traps placed around the bases of the buildings, which were also sampled once a year at the same time as the rooftops.

Cookie Baits

All green rooftops were also surveyed using cooking baits, which were a clear plastic 25 mL test tube filled with about 2.4 grams of Keebler Pecan Sandies. Twenty-five baits were placed across the middle of each green rooftop for one hour during non-rainy days. Baits were placed about every 3 meters along a straight transect across the green rooftop. Rooftops were sampled once between May-August in 2012 and July-August in 2013. To compare the effect of temperature on ant activity throughout the day, the Botanic Garden rooftop was sampled using cookie baits five times over a 12-hour period: 8-9 am, 10:30-11:30 am, 1-2 pm, 3:30-4:30 pm, and 6-7 pm.

Finally, Intrinsic Landscaping followed the same protocol using cookie baits to sample an additional 23 rooftops they were maintained in 2012 and 2013. This sampling was conducted during the same time period of the intensive sampling of our eight green rooftops. Depending on maintenance schedule, rooftops were sampled between 1-4 times each year.

Analysis of Pitfall Traps and Cookie Baits

After samples were taken, pitfall traps were stored at room temperature and cookie baits were stored in a freezer (-10 °C) until they were sorted. Ants caught in pitfall traps and cookie baits were identified to genus and species level using an Ants of Illinois genera key (Wilkins & Menke 2011), and further identified into species level using other regional species keys (Coovert 2005; MacGown 2013). All ants were stored in vials with 95% ethyl alcohol. All other insects caught in pitfall traps were stored in separate vials with 95% ethyl alcohol, and any additional plant debris or fluid was discarded. Voucher specimens from both pitfall traps and cookie baits were point mounted for future reference.

Question 1: Ant Trapping Methods:

Ant species richness was determined by the total number of species captured from each site using both cookie baits and pitfall traps. Differences in ant species richness between pitfall traps and cookie baits on green rooftops were compared using a paired *t*-test (Microsoft Excel). In addition, I created rarefaction curves of standardized species richness across sampling methods based on both the number of samples (pitfalls) and incidences (species occurrences). In sample-based rarefaction curves, the different samples, either pitfall traps or cookie baits, are randomly combined to form a species richness curve (Ellison et al. 2007). Thus, ant species were accumulated for the total number of samples, either pitfall traps or cookie baits. This rarefaction curve was then rescaled to a common x-axis of incidence, occurrence of a species, because there were different sampling sizes for each sampling method (Ellison et al. 2007). EstimateS version 9 ran 500 randomizations of the data for both sets of refraction curves (Colwell 2013).

Question 2: Rooftop and base species composition.

I used a paired *t*-test to compare the species richness from pitfall traps on the green rooftops to those from their bases using Microsoft Excel Data Analysis. Jaccard similarity index was used to determine differences in the composition of ant species between rooftops and bases. To evaluate similarity between rooftops and bases, the abundance-based Jaccard Index was calculated using EstimateS version 9 (Colwell 2013). The Jaccard Index ranges from 0 to 1, where a value of 1 indicates that all species are shared between the two samples, and 0 indicates there are no shared species between the two samples (Ellison et al. 2007). Additionally the Chao2 index was used to estimate asymptotic species richness for rooftops and bases, which was calculated by EstimateS version 9 (Colwell 2013).

Question 3: Rooftop Characteristics:

The ant species richness of the eight intensely studied rooftops was compared to differences in green rooftop area, age, height, rooftop type, and percent vegetation in a 500-meter radius around the rooftop (Table 1). Individual linear regressions of ant species richness on each green rooftop versus their area, age, and percent vegetation were calculated in Microsoft Excel Data Analysis. Differences in ant species richness were also compared using a 2-sample *t*-test to rooftop type, which was either extensive or intensive. To study another important aspect of isolation, green space around each of the intensively sampled eight rooftops was calculated using Quantum GIS. Green space is the vegetation around a rooftop, including shrubs and large vegetation. Green space or percent vegetation around the base of the green rooftop building was traced 2-dimensionally using an aerial photo in a 500 meter radius around the green rooftop (Tonietto & Ascher 2011). Percent vegetation was calculated by dividing the total area of green space around each rooftop by the total area around the rooftop.

Results

In my study, 2,669 individual ants were caught across eight green rooftops with 439 pitfall traps, while 445 ants were caught with 146 pitfalls traps placed around their bases in 2012 and 2013. I also used 503 cookie baits to estimate species richness across these eight green rooftops, while Intrinsic Landscaping used 975 cookie baits to sample the additional 23 rooftops throughout both years. Thirteen species were found across the eight intensively sampled rooftops using pitfall traps and cookie baits, whereas 10 species were found using only pitfall traps around bases in both years. All ant species found in 2013 were found in 2012, while *Crematogaster cerasi, Camponotus pennsylvanicas,* and *Formica pallidefulva*, were only found in 2012. Species richness in pitfall traps on green rooftops ranged from 1-6 (mean ± SE = 2.9 ± 0.6). City Hall, the oldest green rooftop, had the most species richness with 6 ant species. Overall, the most widespread species was *Tetramorium caespitum*, occupying six of the eight green rooftops sampled. There were three species that were found on only one rooftop: *Camponotus nearcticus*, *Formica montana,* and *Formica pallidefulva*. *Tetramorium caespitum* was also one of the most frequently caught species in pitfalls across the eight green rooftops, occupying 31 percent of all pitfall traps. Finally, the cookie baits placed by Intrinsic Landscaping Company, only captured *Tetramorium caespitum* on the green rooftops.

Question 1: Ant Trapping Methods.

When comparing sampling methods, pitfall traps captured every species caught by cookie baits except *Camponotus nearcticus*. Pitfall traps captured nine species that baits did not: *Brachymyrmex depilis, Crematogaster cerasi, Formica montana, Formica subsericea, Formica pallidefulva***,** *Hypoponera opacior, Lasius neoniger, Nylanderia faisonensis,* and *Solenopsis molesta*. Pitfall traps captured significantly more ant species than cookie baits ($t_7 = 2.73$, $P = 0.03$; Fig. 2). On average, pitfall traps captured twice as many ant species as cookie baits (pitfall traps: mean ± SE = 2.9 ± 0.6; cookie baits: mean ± SE = 1.3 ± 0.2). In both sampling methods numerous traps failed to capture ants: 135/339 pitfall traps (40%) and 159/503 cookie baits (32%). The rarefaction analysis of trapping methods revealed that pitfall traps captured on average more species than cookie baits on both a sample bases, either per pitfall or cookie bait, and incidence bases, occurrences of a species (Fig. 3). The shape of the species richness curves for both samples and incidences in pitfall traps did reach an asymptote, as did the species richness curves for cookie baits (Fig. 3).

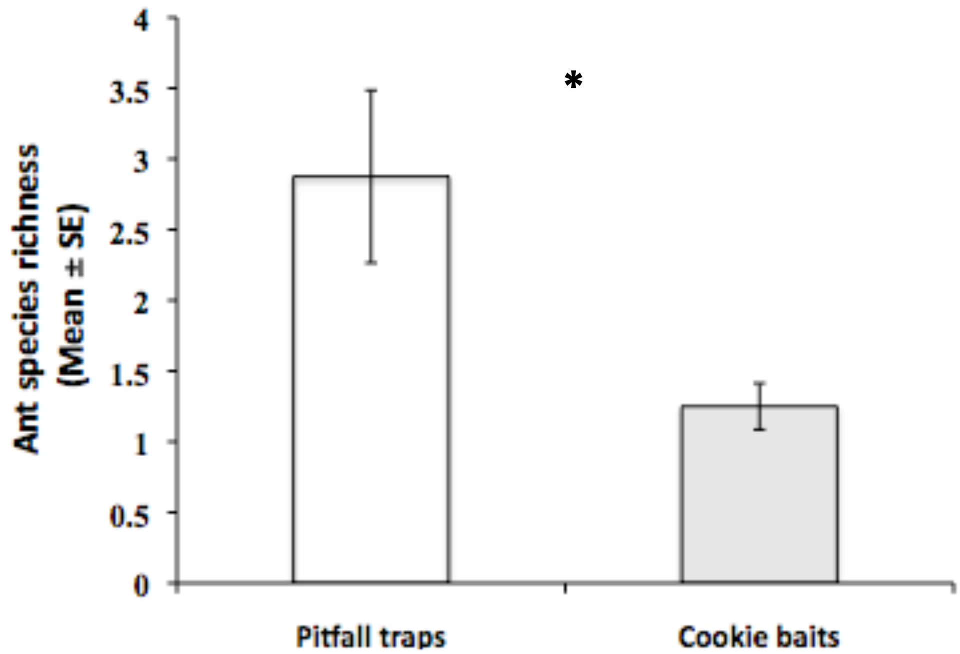

Figure 2. Mean ant species richness (±SE) for pitfall traps and cookie baits. An asterisk represents a significant difference.

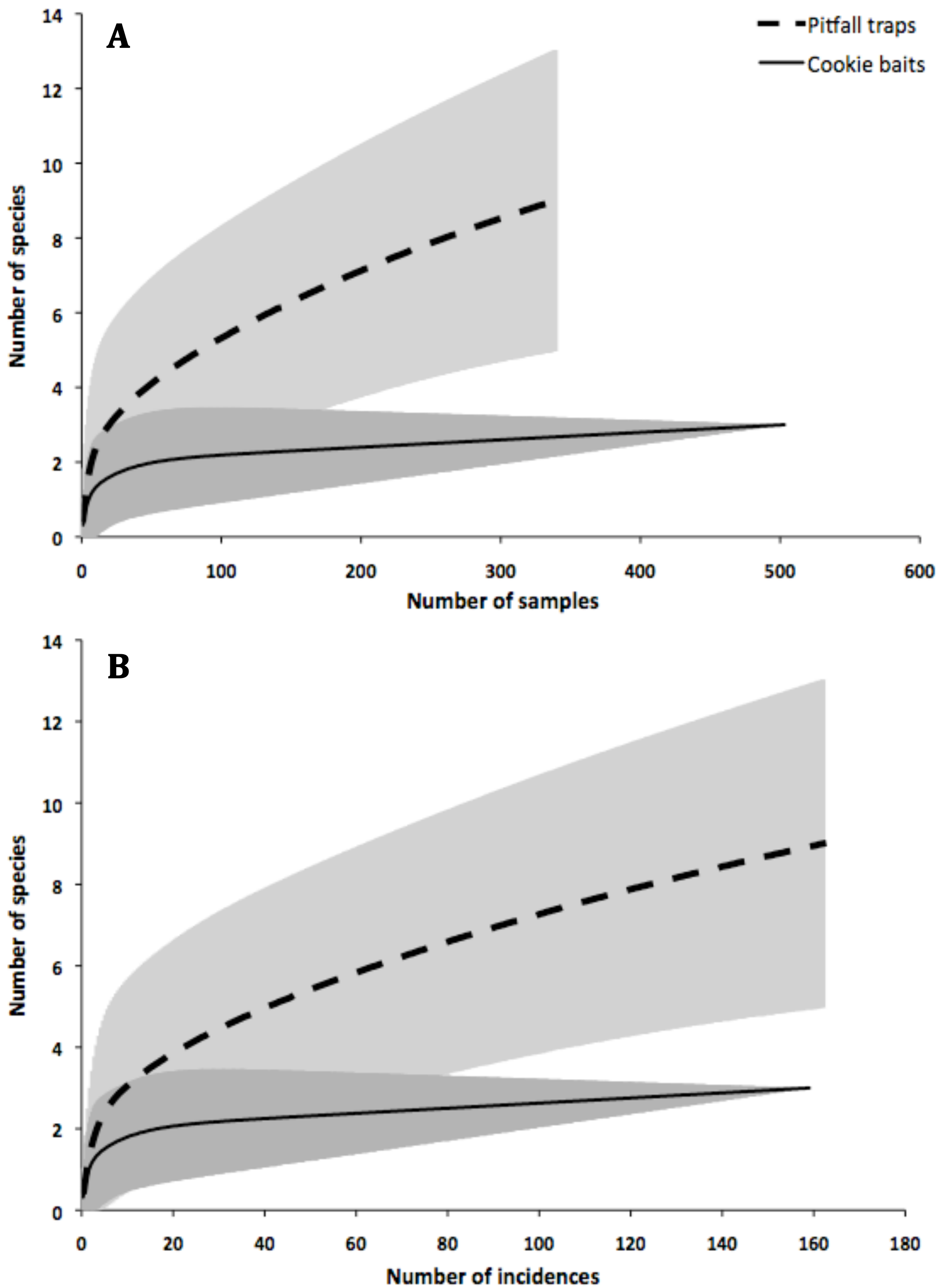

Figure 3: Trap-level refraction curves for two sampling methods. (A) Rarefaction curves based on the number of samples shown with 95% confidence intervals (CIs) (B) Rarefaction curves corrected for incidences with 95% CIs.

Question 2: Rooftop and base species composition.

There was no significant difference between ant species richness across the eight rooftops and their corresponding bases ($t_7 = 0.49$, $P = 0.64$; Fig. 4). Furthermore, when comparing ant species composition between green rooftops and their bases using the Jaccard similarity index, the adjusted compositional similarity was 100%, indicating that the community composition between rooftops and bases was identical.

The Chao 2 estimated species richness for green rooftops was 12 and for bases was 13 ant species (Fig. 5). Large numbers of species, out of the total number, that only occurred once or twice created large confidence intervals (Fig. 5). Four species occurred once on rooftops out of ten species, while three species out of ten species occurred once around buildings.

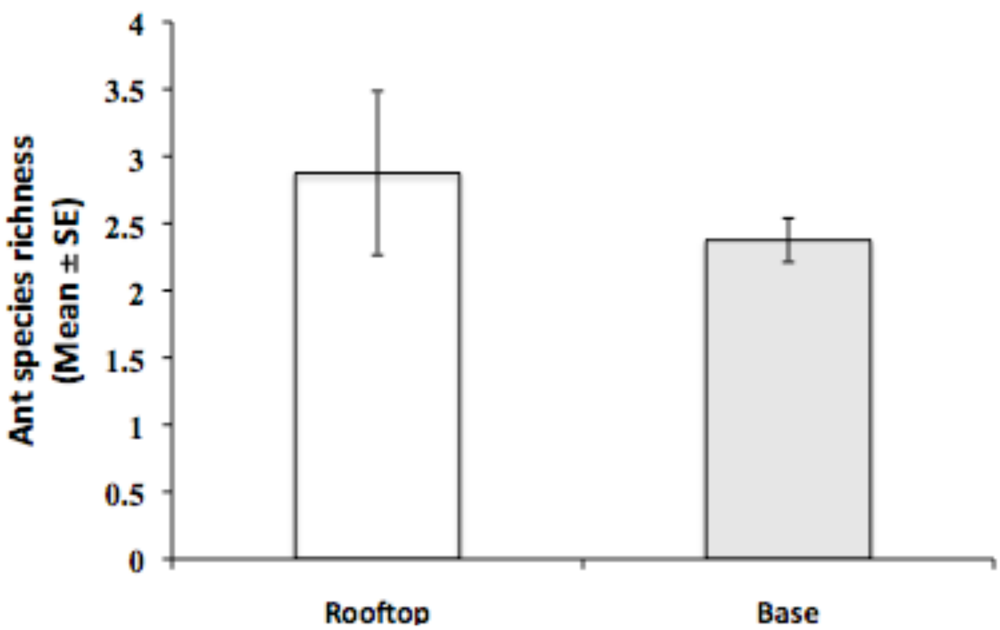

Figure 4. Mean ant species richness (±SE) between rooftops and bases.

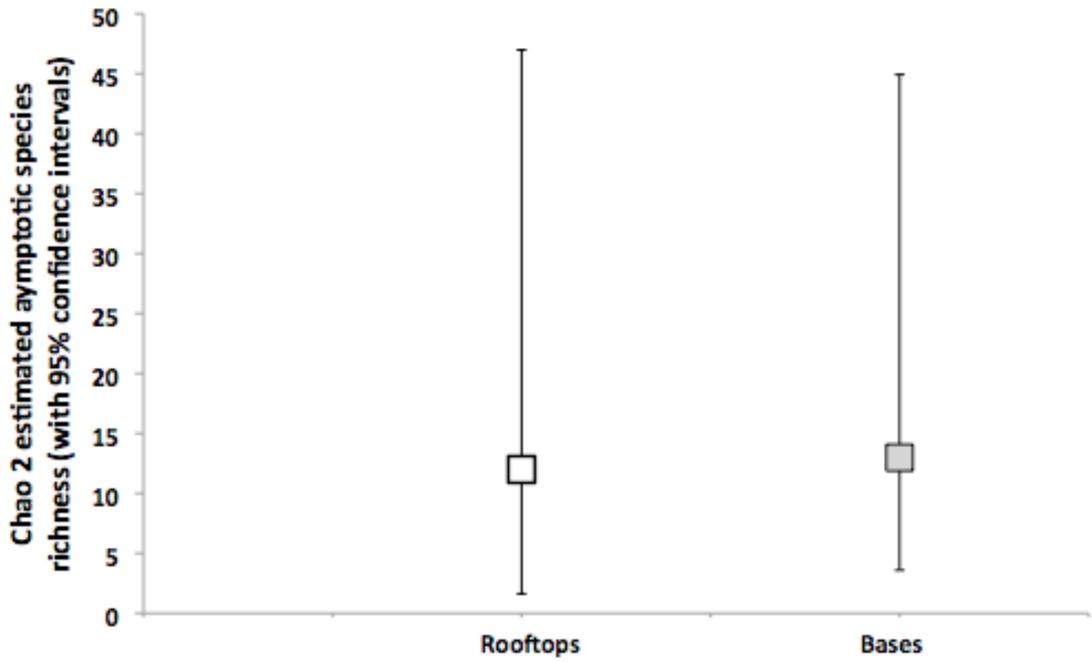

Figure 5. Asymptotic Chao 2 estimate of species richness on green rooftops and bases.

The species unique to rooftops were *Camponotus nearcticus* and *Formica montana*, while those unique to bases were *Camponotus pennsylvanicus* and *Formica subsericea* (Fig. 6). When comparing pitfall traps on green rooftops and bases in 2012 and 2013, *Crematogaster cerasi* was found in 2013 but not in 2012 around the base of the Chicago Botanic Gardens. Also *Camponotus pennsylvanicas* was found around the bases of the Peggy Notebaert Museum and the residential green rooftop in 2012 but not in 2013. Overall, however, most species found in 2012 were also found 2013. *Tetramorium caespitum* was caught in the highest proportion of pitfall traps on rooftops and around bases. The second most common ant species on rooftops, *Tapinoma sessile*, caught in the highest proportion of pitfall traps on rooftops was the seventh most common around bases. *Tetramorium caespitum,* *Tapinoma sessile,* and *Nylandaria faisonensis* were caught in the highest proportion of pitfall traps on rooftops, but *Tetramorium caespitum*, *Nylandaria faisonensis*, and *Lasius neoniger* were caught in the highest proportion of pitfall traps around bases.

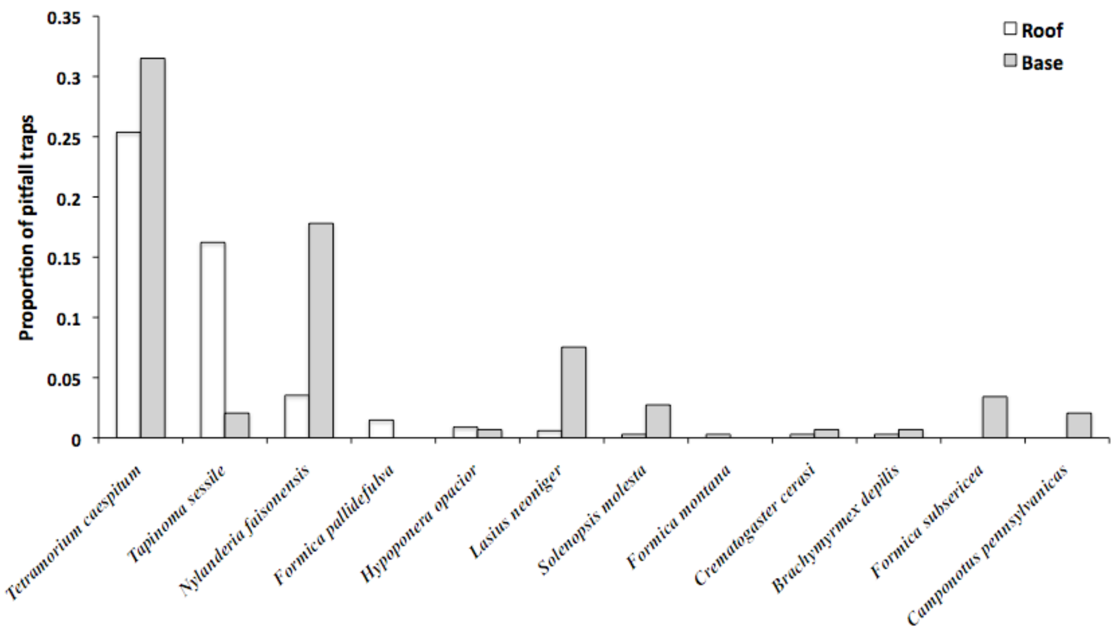

Figure 6. Proportion pitfall traps that captured ants across eight rooftops and bases from 2012-2013.

Question 3: Rooftop characteristics.

Rooftop area did not significantly predict ant species richness, even though the largest green rooftop City Hall had the most species ($F_{1,6}$ = 5.4, P = 0.06, r^2 = 0.47; Fig. 7). Though the oldest green rooftop, 12 years old, had the highest species richness and the third oldest had the second highest species richness, age did not significantly predict ant species richness ($F_{1,6}$ = 2.52, P = 0.2, r^2 = 0.30; Fig. 8). Percent-vegetated area around each rooftop also did not predict species richness ($F_{1,6}$ = 1.24, P = .308, r^2 = 0.172; Fig. 9). Habitat complexity, comparing ant species richness between extensive and intensive green rooftops, was not significant using a two-sample *t*-test ($t_7 = 0.79$, $P > 0.05$).

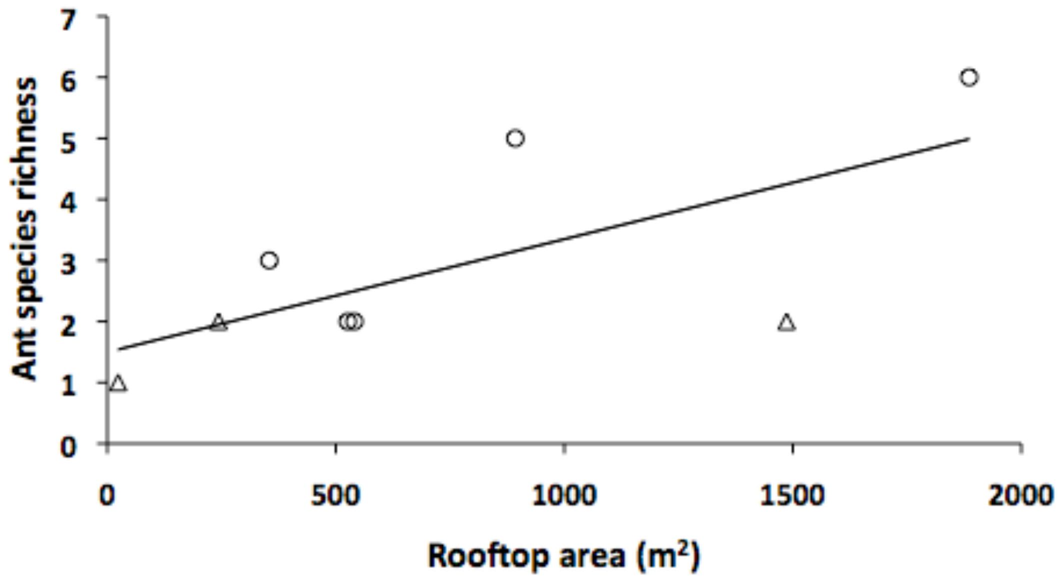

Figure 7. Area of rooftop versus species richness on rooftop from 2012-2013 (extensive green rooftops represented as triangles and intensive green rooftops represented as circles).

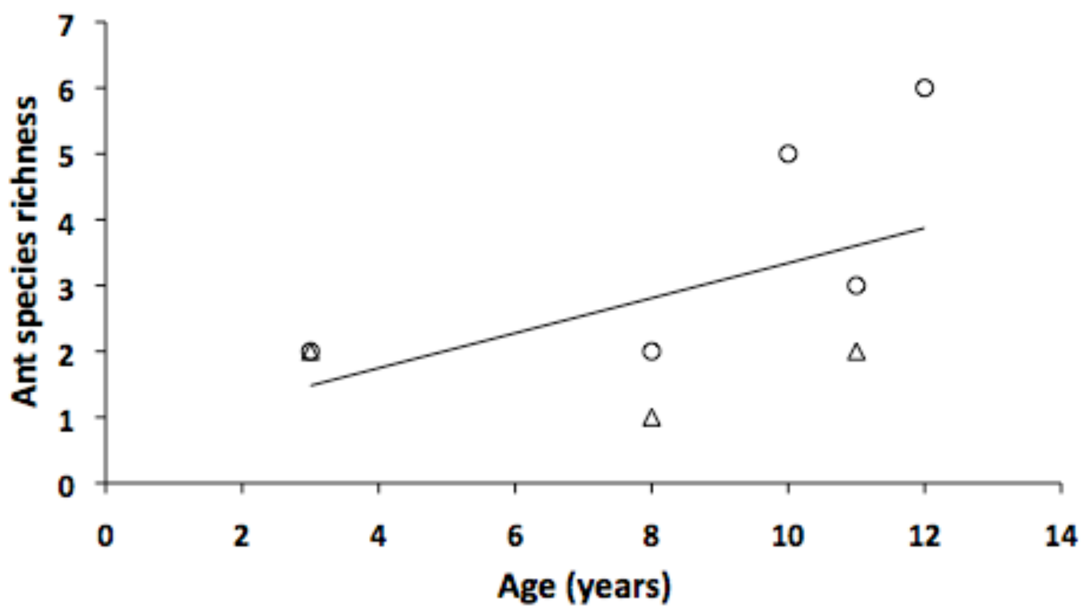

Figure 8. Age of rooftop versus species richness on rooftop from 2012-2013 (extensive green rooftops represented as triangles and intensive green rooftops represented as circles).

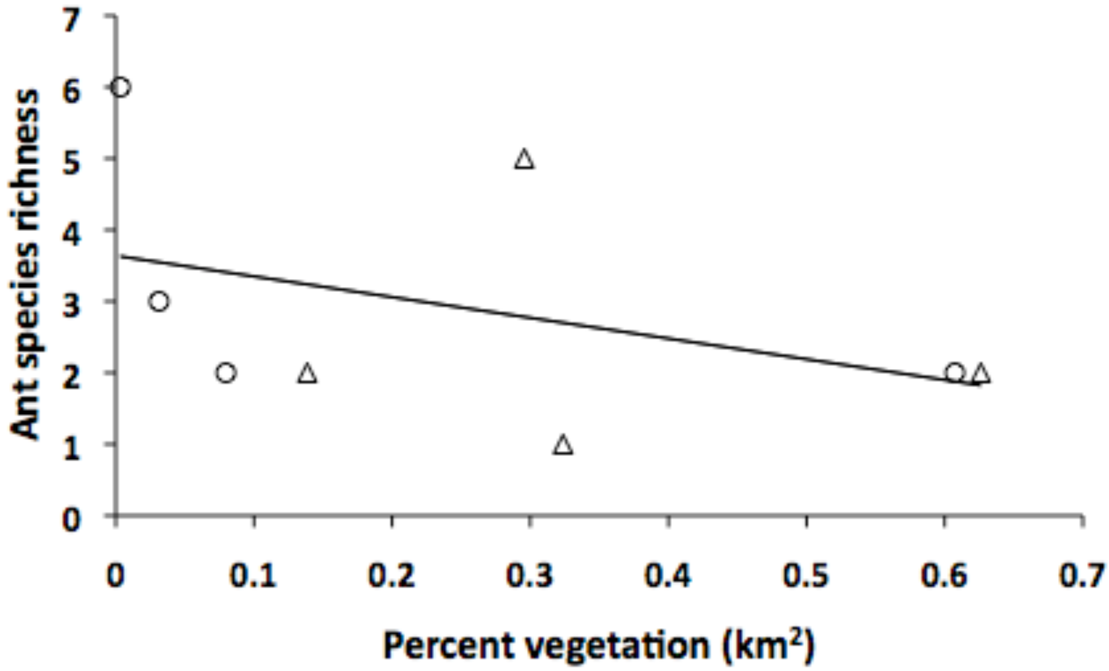

Figure 9. Percent vegetation within 500m of green rooftops versus species richness (extensive green rooftops represented as triangles and intensive green rooftops represented as circles).

Additional Comparisons: Temperatures Affects on Ant Activity

Ant activity, measured at cookie baits throughout a hot day with a high of about 35 °C, diminished past 9 AM. Ant activity was present during early morning and late afternoon (Table 2).

Table 2. Ant activity at cookie baits over an 11-hour period on the Chicago Botanic Garden green rooftop.

Time of day	Temperature (°C)	Ant activity	Percentage of baits with ant activity
8-9 AM	26	Ant Activity	12
10:30-11:30 AM	28	No activity	0
1-2 PM	33	No activity	0
3:30-4:30 PM	35	No activity	0
6-7 PM	34	Ant Activity	24

Additional Comparisons: Intrinsic Landscaping

Tetramorium caespitum was the only ant species found across rooftops sampled by intrinsic landscaping (Appendix A). No other analyses were done with this data.

Discussion

In our study we demonstrated that (1) pitfall traps on average captured significantly more ant species than cookie baits, (2) ant community composition was similar between rooftop and bases, and (3) area, age, height, and distance to nearest vegetated habitat did not predict ant species richness. Our study also provides baseline data for future ant species studies on green rooftops.

Research Area 1: Ant Trapping Methods.

Our study differs from previous work on green rooftops by focusing on sampling ants specifically on green rooftops over a two-year period, and it enhances existing knowledge of ant-sampling protocols that have only been tested on ground-level environments (Kalif et al. 2000; Alder & Silverman 2004; Pacheco & Vasconcelos 2011). While pitfall traps performed the best in my study, litter sampling has been show to be the best method at capturing ant species compared to baiting or pitfall traps in other studies (Olson 1991; Ellison et al. 2007). Litter sifting, which is the removal of ants from a leaf litter layer (Martelli et al. 2004), cannot always be done on green rooftops. This is because green rooftops in general do not get the leaf litter terrestrial environments obtain, so it is an inappropriate method of sampling in this case. Thus, we further examined the use of pitfall traps and cookie baits.

Our study like other ground level studies shows that pitfall traps captured significantly higher ant species richness than cookie baits (Fig. 2). Cookie baits only caught 3 of 13 ant species found across green rooftops. However, cookie baits can be a good method to obtain a general idea of the most dominant or most abundant species on a rooftop (Ellison et al. 2007). The species caught in the highest proportion of baits in both pitfalls and cookie baits was *Tetramorium caespitum*. Cookie baits, thus, would be a sufficient method to find out what ant species are generally active on green rooftops. Ellison et al. (2007) also found this when comparing pitfall traps and cookie baits, where the ant captured in the most traps, *Aphaenogaster rudis*, was also the ant captured in cookie baits. Cookie baits, thus, can provide a starting poin for the ant species most likely to be caught in other methods of ant capture.

Limitations in this portion of the study included dealing with sampling on different days with varying temperatures. Previous research on temperature and its affect on ant activity has shown that ants remain more nocturnal during hot summer months, with some activity in the mornings and afternoons (Gamboa 1976). This can be problematic, especially when sampling is done on buildings, where rooftops are exposed to a harsher environment of higher temperatures and heavier winds (Oberndorfer et al. 2007). Thus ant activity, while using cookie baits, may be lower throughout the day as temperatures tend to rise on top of a green rooftop. In this study, having different sampling times may have been an issue, except all of the eight intensively sampled green rooftops received ants at the cookie baits at least once when sampled in 2012 and 2013. However, ant species richness at cookie baits may have still been affected because of the sampling times. We explored this further by sampling a rooftop from the morning into the late afternoon, and we found ant activity only in the morning and late afternoon (Table 2). This certainly may have influenced results when working with cookie baits. Thus, future work should focus on ant activity during varying temperatures of days and months.

Another important aspect involved in an ant's ability to gain access to cookie baits is the dominance and aggression found in certain ant species. Aggression affects ant species and their desire to attack, avoid, or coexist with another species (Fellers 1987). In ant communities, two types of competition occur: interference and exploitation (Fellers 1987). Interference, seen in the behavior of Argentine ants, is where ant species prevent other species from gaining resources through aggressions, poisons, and territoriality (Fellers 1987; Human & Gordon 1996). Invasive ants in places like California have prevented foraging of native ant species by biting antennae of other ant species, and also by preying on winged queens from native ant species (Human & Gordon 1996). In contrast, exploitation is where one ant species finds and exploit resources before other species, and this has been show in "nectar-thieving" ant species (Fellers 1987; Lach 2005). For example, *Anoplolepis gracilipes* has the ability to take between 5-11 times the amount of nectar compared to other ant species in Hawaii (Lach 2005). Thus, these interactions between ant species communities contribute to their abilities to gain access to cookie baits.

Dominance within ant species interactions is not only attributed to aggression, but also with their numbers. For instance, there is positive correlation between an ant's body size and food consumption (Fellers 1987; Cerda 1998). However, smaller ant species are able to overcome larger ant species through mass-recruitment and cooperative carrying of food particles (Cerda 1998). In this study, the ants caught in the highest proportions of baits, *Tetramorium caespitum* and *Tapinoma sessile*, follow these social mechanisms of mass recruitment. *Tapinoma sessile* has been shown to dominate the urban landscape despite its subservient behavior seen in many natural environments (Buczkowski & Bennett 2008; Menke et al. 2010). Consequently, this species continues to succeed in the presence of dominant species perhaps by its ability to maintain large colonies allowing it to recruit and take advantage of more food sources (Buczkowski & Bennett 2008; Menke et al. 2010). *Tetramorium caespitum* exhibits similar methods of foraging, where group recruitment is achieved through the use of a pheromone trail causing this species to swarm along a defined trail (Beckers et al. 1989). *Tetramorium caespitum* has also been found to exhibit signs of aggression where its aggressive behavior can be quantified by mandible openings, seizings, and gaster flexing (Vroey 1979). These behaviors were seen in cookie baits for this study where *Tetramorium caespitum* would completely dominate baits and carry most of the cookie away. This happened on most of the green rooftops, where *Tetramorium caespitum* would take over a cookie bait despite the presence of other ant species. Overall, it appears that ant dominance and aggression did affect ant species richness.

Question 2: Rooftop and base species composition.

Most studies on ant species richness have focused generally on arthropod communities and other insects such as bees and wasps (Kadas 2006; MacIver & Lundholm 2011). Again not much research on ant colonization of green rooftops has been conducted over long periods of time while also comparing ant communities on the ground. Through our study we are able to add to current research primarily focused on insects and looking at a rooftop's potential to support insect diversity (Baumann 2006; Brenneisen 2006). This study builds on this research because it compares ant species richness of green rooftops to their adjacent environments, while also showing its potential in supporting insects. Just like the few other studies comparing adjacent habitats (MacIvor & Lundholm 2011), we found species richness on green rooftops did not significantly differ from the species richness around their bases (Fig. 4).

This research also adds to previous work done on the distribution of certain ant genera within Chicago and suburban areas. The most common ant species found on green rooftops and their bases was *Tetramorium caespitum* (Fig. 6), while Gregg (1944) found that this invasive species from Europe was rare around Lake Michigan. This study supports current research showing that *Tetramorium caespitum* is found in more disturbed sites such as cities and has spread widely across the United States (Buczkowski & Richmond 2011). The second most abundant species found across our eight green rooftops, *Tapinoma sessile*, also supports research showing that this species of ant is highly flexible because it is found in both natural and manmade environments (Buczkowski & Richmond 2011).

Both species have been shown to dominate urban environments and become dependent on urban dwellers for food and a place to live, thus allowing them to potentially successfully colonize green rooftops (Buczkowski & Bennett 2008). The third most common ant caught in pitfall traps across rooftops, *Nylanderia faisonensis*, also exhibits the trait of being a rapid forager that finds baits first and recruits other individuals quickly from the colony (LaPolla et al. 2011). However, this species of ant may not be as successful as *Tetramorium caespitum* and *Tapinoma sessile* because they do not defend their resources against other species of ants (LaPolla et al. 2011).

When looking on the ground around the building of our intensively sampled green rooftops, *Tetramorium caespitum* and *Nylendaria faisonensis* were still the among the highest proportion of ants caught, but *Tapinoma sessile* was not found as frequently in traps as it was on rooftops. This again may be due to its ability to conquer new man made habitats such as green rooftops, while also maintaining its dominance through recruitment of other ant workers (Cerda 1998). *Tapinoma sessile* may not exhibit the same ability to dominate the bases of green rooftop buildings where there are more species to interact with such as *Formica subsericea, Lasius neoniger,* and *Camponotus pennsylvanicas*. *Lasius neoniger* may be rare on green roofops but common around their bases because they are mound builders and successful in open habitats such as fields and turfgrass (Maier & Potter 2005). *Lasius neoniger* colonies can build over 20 mounds per square meter with branching networks as deep as 70 cm, which is larger than the soil depth on all of green rooftops in this study (Maier & Potter 2005). *Tetramorium caespitum*, however, mostly is found under logs, exposed soil under pavement, and even sometimes in homes (Antonelli & Glass 2006). The nests of *Tapinoma sessile* also tend to be shallow, where they are found under stones, in mulch, or even protected in manmade structures (Buczkowski & Bennett 2008). Thus, these factors may influence why this ant species, *Lasius neoniger*, was not as common on rooftops as *Tetramorium caespitum* and *Tapinoma sessile*. Also, *Formica subsericea* and *Camponotus pennsylvanicas*, were not found on rooftops potentially because it does not meet the requirements of their preferred habitats. *Camponotus pennsylvanicas* is found mostly around large trees such as oak trees, whereas *Formica subsericea* are found around dry hillsides and nest in deep soil nests (Wesson & Wesson 1940). These species therefore do not seem to be compatible with rooftops lacking trees, limiting soil depths, and maintained by watering systems.

Question 3: Rooftop characteristics.

Current research has shown no comparisons of ant species richness between rooftops with differing characteristics in soil depth, age, vegetation cover, and vegetation type, however, general arthropod communities have been studied (Kadas 2006; Schindler et al. 2011; Madre et al. 2012). Previous studies have found that the number of arthropod species on a green rooftop are not predicted by rooftop size, height, or distance to nearest vegetated habitat along with conflicting views on how green rooftop vegetation diversity may or may not affect arthropod diversity (Schindler et al. 2011). Similar to what Schindler et al. (2011) found with arthropods on green rooftops, over two years of sampling rooftops we found species richness was not significantly predicted by green rooftop soil depth, age, and percent vegetation around the rooftop (Fig. 7, 8, & 9). Further study should be continued concerning how vegetation type may affect ant or arthropod diversity because there are conflicting views on whether vegetation area or complexity on green rooftops affects ant species richness (Schindler et al. 2011; Madre et al. 2012). Studying these factors may help design better rooftops for promoting colonization.

The metaphor of islands in the sky may not apply to the equilibrium theory of island biogeography because species richness may not always depend on isolation of green rooftops, which includes their proximity to other green areas, age, or height of the green rooftop. This leads to further questioning of what may cause this discrepancy between green rooftops and the island biogeography theory. The presence of humans is an aspect of the island biogeography theory not taken into account with urban environments, possibly creating a need for a new theory that takes this into consideration (Niemelä 1999). On green rooftops, human activity can violate the assumptions of the island biogeography theory by transporting ant species onto green rooftops (McGlynn 1999). Transportation of ants on green rooftops may occur when an individual is moving soil and planting vegetation, which may introduce species into an area that were not capable of being introduced before, possibly affecting the results of this study. More observation over a larger span of time and the addition of more rooftops may answer whether island biogeography is truly applicable to urban environments.

Chapter 3 – Final Word

Conclusion

The lack in significant difference between ant species richness and composition on green rooftops and their bases suggest that green rooftops are successful at providing environments for organisms in urban areas (MacIvor & Lundholm 2011). The lack of significance seen between ant species richness and green rooftop traits such as height, adjacent vegetation area, and even age may suggest a need to find other green rooftop traits that may correlate with higher ant species richness. However, our data may not have included enough variability in our rooftops, for instance in area, age, height, and even percent vegetation around the rooftop. Thus, the addition of rooftops may benefit our comparisons of these characteristics to ant species richness. This can help developers design better green rooftops, allowing these habitats to thrive with higher diversity.

Diversity of organisms in cities is beneficial not only to the organisms that are endangered by urbanization but also to humans (Dearborn & Kark 2010). Overall, maintaining biodiversity through green rooftop efforts can conserve important or rare species, provide ecosystem services, and improve human well-being (Dearborn & Kark 2010). Diversity in urban environments, with insects and birds, might be important in providing pollinators and seed dispersers for urban agriculture (Mendes et al. 2008). Maintaining biodiversity in cities may also maintain soils, sustaining hydrological cycles, store and cycle nutrients, supply clean air and water, absorb and detoxify pollutants, decompose wastes, and enhance the pollination of plants (Myers 1999). Specifically maintaining biodiversity of ants is important because it has been shown that ant species richness correlates with plant species, invertebrate species, and microbial biomasses (Folgarait 1998). Thus, understanding specifically how green rooftops can influence biodiversity of ants, can help create a healthier environment for organisms and humans to live in.

Further work may be done looking at the affects of urbanization on ant species found between urban areas and more rural areas. There was no significant correlation between ant species richness and increasing vegetation area, however, it would be interesting to see how ant species change across an urban-rural gradient on green rooftops, especially because no work regarding this has been conducted. Such information can lead to a greater understanding of how certain green rooftops characteristics can be used to benefit human populations and other organisms that occupy cities.

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Appendix A. Green rooftops sampled by Intrinsic Landscaping.

Green rooftop name/address	Date sampled	Time of day bait is opened	Time of day bait is closed	Temperature (Celcius)	Weather	Soil Depth (cm) or rooftop type	Percentage of ant species with ants	Height of rooftop
Access Living	7/25/12	1:00 PM	2:00 PM	29	Sunny	7.6-15.2	0	5
Big Fedex	7/24/13	2:30 PM	3:00 PM	24	Sunny	12.7	0	3
Big Fedex	7/24/13	8:40 AM	9:45 AM	24	Sunny	12.7	0	3
Big Fedex	7/24/13	10:30 AM	11:30 AM	29	Sunny	12.7	0	3
Big Fedex	7/24/13	1:30 PM	2:30 PM	24	Sunny	12.7	0	3
1400 Kensington Oak Brook, IL	6/19/12	7:55 AM	8:55 AM	24	Sunny	Extensive	4	2
1400 Kensington Oak Brook, IL	9/17/12	10:30 AM	11:30 AM	24	Sunny	2.5-15.2	16	2
Little Village Library	7/31/12	1:00 PM	1:45 PM	32	Sunny	10.2-12.7	0	1
Little Village Library	7/23/13	1:30 PM	2:30 PM	24-27	Sunny	12.7	0	1
Jewel-3630 N.Southport Ave. Chicago IL	7/24/12	9:30 AM	10:40 AM	30	Sunny/Cloudy	12.7	12	2
Jewel-3630 N.Southport Ave. Chicago IL	6/26/12	10:15 AM	11:15 AM	27	Sunny	10.2	0	3
Jewel Desplaines	7/24/12	10:30 AM	11:30 AM	29	Cloudy	10.2	0	3
Jewel Desplaines	8/1/12	10:00 AM	11:00 AM	27	Sunny	10.2	8	3
Jewel Desplaines	9/19/12	7:30 AM	8:45 AM	18	Sunny	10.2	8	3
Presidential Towers	9/18/12	11:15 AM	12:15 PM	18	Sunny	10.2-15.2	16	2
550 West Adams	9/18/12	9:10 AM	10:10 AM	13	Sunny	12.7-17.8	0	19
330 W. Briar Cliff Rd. Bollingbrook, IL	6/26/12	10:00 AM	11:30 AM	25	Sunny	10.2	0	4
Dupage administration 104 N. County Farm Rd. Wheaton, IL	6/19/12	8:30 AM	9:50 AM	29	Sunny	Extensive	0	3
Dupage administration 104 N. County Farm Rd. Wheaton, IL	9/12/12	1:00 PM	2:00 PM	26	Sunny	2.5-15.2	16	1
Dupage administration 104 N. County Farm Rd. Wheaton, IL	7/23/13	11:45 AM	12:45 PM	24	Sunny/Cloudy	15.2	0	2
2300 W. St.Paul Ave. Chicago Il	6/20/12	12:00 PM	1:00 PM	34	Sunny	10.2	4	2
1407 E 60th Street Chicago Theological	6/19/12	9:35 AM	10:35 AM	32	sunny	5.1-12.7	0	2 story and 3 story
1407 E 60th Street Chicago Theological	7/30/12	12:30 PM	1:45 PM	32	Sunny	12.7-17.8	36	3
Patriot Blvd, Glenview	8/5/12	7:30 AM	8:30 AM	18-24	Sunny	12.7	0	1
Brighton Park School	7/15/12	10:30 AM	11:30 AM	32	Sunny/ Partly cloudy	10.2	0	3
UNO Charter School	7/15/12	9:00 AM	10:00 AM	29	Sunny	Extensive	0	2
UNO Charter School	7/22/13	8:30 AM	9:15 AM	24	Sunny	12.7	0	3
S&C Electric	7/30/12	8:00 AM	8:45 AM	24	Sunny	10.2-15.2	0	3
1000 E. 73rd Chicago, IL-Greater Grand Public Library	6/19/12	8:00 AM	9:00 AM	31	Sunny	10.2	0	1
1000 E. 73rd Chicago, IL-Greater Grand Public Library	7/30/12	11:00 AM	11:45 AM	29-32	Sunny	10.2-12.7	16	2
Fountaindale Library	7/23/13	7:30 AM	8:30 AM	18	Cloudy	10.2	0	3,4
2320 E 93rd Street-Trinity Hospital	6/19/12	1:00 AM	2:00 AM	35	Sunny	10.2	0	2
Rush	9/19/12	10:30 AM	11:30 AM	20	Sunny	Extensive	0	4
Jewel-1730 S Marshfield	7/24/12	11:00 AM	11:30 AM	29-32	Sunny	7.6-12.7	0	2
Jewel-1730 S Marshfield	6/26/12	8:25 AM	9:25 AM	24	Sunny	7.6	0	3
Ritz Carlton	7/22/13	10:30 AM	11:30 AM	27	Sunny	30.5/Intensive	0	13
1369 E. 59th St.	10/1/13	10:00 AM	11:30 AM	21	Cloudy		0	

Appendix B. Ant species found on green rooftops using pitfall traps.

Species	Botanic Garden	CCGT	City Hall	Christy Webber	Lake County Permit Center	Peggy Notebaert Museum	Pepsico	Residential
Brachymyrmex depilis						X		X
Crematogaster cerasi			X					
Formica montana					X			
Formica pallidefulva			X					
Hypoponera opacior			X				X	
Lasius neoniger			X			X		
Nylanderia faisonensis		X		X		X		
Tapinoma sessile		X	X			X		
Tetramorium caespitum	X		X	X	X	X	X	
Solenopsis molesta							X	

Appendix C. Ant species found using pitfall traps around the bases of buildings with green rooftops.

Species	Botanic Garden	CCGT	City Hall	Christy Webber	Lake County Permit Center	Peggy Notebaert Museum	Pepsico	Residential
Brachymyrmex depilis								X
Camponotus pennsylvanicas						X		X
Crematogaster cerasi	X							
Formica subsericea								X
Hypoponera opacior						X		
Lasius neoniger	X					X		
Nylanderia faisonensis		X		X		X		
Tapinoma sessile						X		
Tetramorium caespitum	X	X		X	X	X		X
Solenopsis molesta						X		